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# Review of Test Facilities for Distributed Energy Resources

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Sandia National Laboratories

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# REVIEW OF TEST FACILITIES FOR DISTRIBUTED ENERGY RESOURCES[1]

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## Abstract

Since initiating research on integration of distributed energy resources (DER) in 1999, the Consortium for Electric Reliability Technology Solutions (CERTS) has been actively assessing and reviewing existing DER test facilities for possible demonstrations of advanced DER system integration concepts. This report is a compendium of information collected by the CERTS team on DER test facilities during this period

[1] The work described in this report was coordinated by the Consortium for Electric Reliability Technology Solutions, and funded by the Assistant Secretary of Energy Efficiency and Renewable Energy, Office of Power Technologies of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098 and DE-AC04-94AL85000 and by the California Energy Commission, Public Interest Energy Research Program, under Work for Others Contract No. BG 99-396 (00).

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## Acknowledgment

The authors wish to thank the staff at the various test facilities that responded to the survey questionnaire or provided the information for this report. They include:

Tom Bialek, Pacific Gas & Electric;
Stephanie Hamilton and Robert Yinger, Southern California Edison, on behalf of University of California, Irvine;
Ron Johnson and Dennis Witmer, University of Alaska, Fairbanks;
Kathy Torok and Ray Marion, University of Wisconsin, Madison
Peter Johnston, Arizona Public Service Company and Bob Hammond, Arizona State University providing additional information for the STAR center;
Tom Key, EPRI PEAC;
Jim Buckley on behalf of Chugach Electric Association, Anchorage, AK.

The original surveys and information on the various test facilities was gathered in 2000. Since that time, there was an evolution of the CERTS Microgrid concept and a better understanding of the testing needed to validate it. Consequently, follow-on surveys included adding information on American Electric Power Dolan Technology Center and updating the information for Pacific Gas & Electric's Distributed Generation Test Facility. The authors wish to thank Dave Nichols and Ken Loving, AEP Dolan Technology Center, for using the original survey questionnaire and providing the information for their facility shown in Section 3.2.1. The authors also wish to thank Garth Corey, Sandia National Laboratories, for visiting the PG&E facility in September 2001 and providing the updated information on the facility included in Section 3.2.2.

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# 1. Introduction

Since initiating research on integration of distributed energy resources (DER) in 1999, the Consortium for Electric Reliability Technology Solutions (CERTS) has been actively assessing and reviewing existing DER test facilities for possible demonstrations of advanced DER system integration concepts. This report is a compendium of information collected by the CERTS team on DER test facilities during this period.

The information contained in this report was developed in two stages. In the initial stage, a structured questionnaire was sent to selected facilities known by the project team to be engaged in DER technology testing. Information on both the experience of these facilities with specific DER technologies and the testing capabilities available at the facilities, was collected. The completed questionnaires and narrative information provided by respondents (in lieu of completed questionnaires) are included in this report (section II).

In the second stage, information developed during the first stage was re-assessed and additional information was collected for the specific purpose of evaluating the capabilities of facilities to support testing of aspects of the CERTS Microgrid concept.[1] (Lasseter, et al 2002). As a result, the project team developed additional information on the AEP Dolan Technology Center and on the PG&E test facilities in San Ramon, CA (section III).

[1] Lasseter, R., A. Akhil, C. Marnay, J. Stevens, J. Dagle, R. Guttromson, A. S. Meliopoulous, R. Yinger, and J. Eto. 2002. *Integration of Distributed Energy Resources: TheCERTS Microgrid Concept*.

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# 2. Initial Survey of DER Technology Testing Facilities

An initial survey was conducted between 1999 and 2000 to identify facilities and resources where distributed generation and storage systems were being tested. The purpose was to identify sources of data or test capabilities that would support current and future CERTS activities in the area of distributed generation modeling and markets.

A prepared questionnaire was sent to several entities to identify specific capabilities and resources available for distributed generation testing. However, due to the diversity of capabilities and function, not all entities responded to the questionnaire alone. Instead some chose to provide a narrative description of the operations. Table 1 identifies the entities polled and their preferred response mode:

**Table 1. Responses from Distributed Generation Test Facilities.**

| Name | Response |
|---|---|
| Pacific Gas & Electric | Questionnaire |
| University of California - Irvine | Questionnaire |
| University of Alaska - Fairbanks | Questionnaire |
| University of Wisconsin - Madison | Questionnaire |
| Arizona Public Service Company | Narrative |
| Sandia National Laboratories | Narrative |
| Oak Ridge National Laboratory | Narrative |
| National Renewable Energy Laboratory | Narrative |
| USDA CPRL, Bushland, TX** | Narrative |
| EPRI PEAC | Narrative |
| Nevada Test Site* | Narrative |
| Chugach Electric | Narrative |
| Allied Signal, Albuquerque Operations | Narrative |

* Information obtained through third party sources

** Included in Sandia Laboratories write-up

The testing performed at the various entities polled for this survey supports a wide range of needs. The national laboratory testing generally supports technology development at the subsystem and system levels and the technologies tested are the ones where the lab has existing technology development efforts. Testing conducted in photovoltaics, wind and fuel cells are examples, although the recent high level of interest in microturbines has prompted new initiatives in this technology as well. The universities are responsive to their curriculum needs as well as industry or government sponsored research. The utility testing is distinctly different and generally focuses on operational data and technology characterization. Similarly, testing at the vendor facilities is focused on component and system development.

Testing conducted by utilities has undergone a significant decline due to severe cuts in R&D programs. There are only one or two utilities that are actively conducting testing and evaluation of distributed technologies at their own research facilities. The Arizona Public Service Company efforts included in this survey are a notable exception. The Pacific Gas & Electric facility has good infrastructure but at the time of the survey was not currently engaged in distributed technology systems testing.

Table 2 summarizes the technology test capability at each of the entities polled.

**Table 2. Technology Area(s) for Each Survey Participant.**

| Name | MT | FC | PV | BSt | Wi | FW | Inv |
|---|---|---|---|---|---|---|---|
| Pacific Gas & Electric | | X | | X | | | X |
| University of California – Irvine | X | X | | | | | |
| University of Alaska – Fairbanks | | X | | | | | |
| University of Wisconsin – Madison | | | | | | | X |
| Arizona Public Service Company | X | X | X | X | | | X |
| Sandia National Laboratories | | X | X | X | X | | X |
| Oak Ridge National Laboratory | X | | | | | | |
| National Renewable Energy Lab | | | X | | X | | |
| USDA CPRL, Bushland, TX** | | | | | X | | |
| EPRI PEAC | X | X | | | | X | X |
| Nevada Test Site* | | | X | | | | |
| Chugach Electric | X | X | | | | | |
| Allied Signal, Albuquerque | X | | | | | | |

MT = Microturbines; FC = Fuel Cells; PV = Photovoltaics; BSt = Battery Storage; Wi = Wind; FW = Flywheels; Inv = Inverters/Power conversion systems

The responses to the questionnaires and narrative description provided for each facility (in lieu of completed questionnaires) are presented on the following pages.

## 2.1 PG&E Technical and Ecological Services

**PG&E Technical and Ecological Services**
**Distributed Generation Test Facility**
***Survey of Test/Lab Facilities***

**Date of response:** 2/1/00

**Facility Name:** PG&E Technical and Ecological Services
Distributed Generation Test Facility

**Facility Location (City, State):** San Ramon, CA.

**Contact Information:**
Management (Name, phone/fax, e-mail): Dixon Kerr, 925-866-5290, rdk2@pge.com
Technical (Name, phone/fax, e-mail): Tom Bialek, 415-973-0260, tob2@pge.com
Al Beliso, 925 866-5678/5981, axb4@pge.com

**Facility Ownership (Industry owned, Government funded, University, Other grant support):** Pacific Gas and Electric Company

**Operational Date (Date facility was commissioned or commenced testing activity):** June 1988

**Staffing:** PG&E Technical & Ecological Services
Professionals: 80
Technicians: 43
Operators:

**Current Funding Level:** $18 Million

**Dominant Funding Source:** California Gas & Electric rate payers with some third party funding

**Size of Facility (Estimated area in square feet or acres, number of buildings, number of test bays, fenced enclosures):** Overall 13 acres. DGTF 2800 sq. ft.

**Describe any specialized test equipment used:** Simplex Load Banks 400 kW and 300 kVar, (5 kW and 3.75 kVar increments).

**Grid-connected or stand-alone:** Grid and Island

**Test Voltages and Power levels:** 480 500 kVA, 480 1.5MVA

**Types of loads used for testing (Passive, active; resistive or induction and indicate sizes in kW or MW):** 400 kW resistive, 300 kVar reactive

**Test Activity (This information may be repeated for different technologies and systems):**

- **ASC Cryogenic Inverter:** Evaluation of self contained 100 kW liquid nitrogen cooled power inverter.
- **Battery Storage Evaluations:** (1) 250 kW grid-connected, modular energy storage system (AC battery), used for customer/utility peak shaving. (2) Off-line UPS (PQ2000) having ability to detect utility power quality disturbances, switch the load to battery backup, and provide reserve power of up to 2 MW for 10 seconds.
- **Commercial Battery Test Facility:** Performance testing of a variety of batteries from different manufacturers used for energy storage and utility peak shaving.
- **Molten Carbonate Fuel Cell:** Performance testing of a natural-gas fueled, 70 kW molten carbonate fuel cell system, in order to determine overall efficiencies and gather detailed operational data.
- **Natural Gas Genset:** Performance testing of engine-driven generators to determine overall system efficiencies and power quality. Included testing of fixed speed, synchronous generators and a variable speed generator.
- **PV Simulator and Inverter:** Evaluation of dual DC power supply (consisting of two independent, 6 pulse, phase-controlled rectifiers).
- **Superconducting Magnetic Energy Storage:** Evaluated use of liquid helium cooled superconductor to store energy to bridge voltage sags. When sag is detected, system immediately rebuilt voltage.
- **Wavedriver:** Evaluation of bi-directional 60 kW power converter to operate as a static VAR compensator or voltage source inverter.

**Test Objective (Technology evaluation, performance characteristics, technology development support):** Performance Characteristics

**Type of technology or system:**

**Size of system (Power rating – kW or MW; Energy rating – kWh or MWh; for storage systems):** 500 kW IPP, up to 2 MW island

**Duration of testing:**

**Test Dates (Indicate if on-going, or expected end-date):**

**Purpose of testing:**

**Type of data collected:** Measurement systems are designed based on the needs of the system under test and can include temperature, pressure, flow, electrical properties, power quality, vibration, acoustics, and emissions.

*Parameters, number of channels, sampling frequency*
*Attach a sample data dump (Optional)*

**Describe data collection software (Commercial application software or internally developed; capability, operating system platform):** Varies by project. Mostly internally developed software used for data collection. Some commercial data acquisition and analysis software also used.

**Computer models used at Facility (Commercial or developed in-house; current and past usage):**

## 2.2 University of California, Irvine - Southern California Edison Test Facility

**University of California, Irvine -**
**Southern California Edison Test Facility**
***Survey of Test/Lab Facilities***

**Date of response:** 1/31/00

**Facility Name:** University of California, Irvine / Southern California Edison Test Facility

**Facility Location (City, State):** Irvine, California

**Contact Information:**

| | |
|---|---|
| Management (Name, phone/fax, e-mail): | Stephanie Hamilton, 626 302-8937, hamiltsl@sce.com |
| Technical (Name, phone/fax, e-mail): | John Auckland, 619 447-6641, 949 824-1699, jaucklan@home.com |

**Facility Ownership:** University of California, Irvine owns site, Southern California Edison with DOE, CEC, EPRI owns site modifications and microturbines

**Operational Date:** January 1999.

**Staffing:**
Professionals: 1
Technicians: 2 (operators and technicians)
Operators:

**Current Funding Level:** $2.1 million

**Dominant Funding Source:** DOE, CEC, EPRI, SCE

**Size of Facility (Estimated area in square feet or acres, number of buildings, number of test bays, fenced enclosures):** Approximately 600 square feet, outdoors, 4 test bays enclosed by one fence

**Describe any specialized test equipment used:** Scientific Campbell Continuous Data Acquisition for flows, temperatures and power, Total Flow Analyzer for continuous fuel composition and fuel heating value, BMI PQNode for power quality, harmonic distortion

**Grid-connected or stand-alone:** Grid connected

**Test Voltages and Power levels:** 480 VAC, three phase, 4 wire, site rated for 400 amps, about 330 kVA.

**Types of loads used for testing (Passive, active; resistive or induction and indicate sizes in kW or MW):** Passive, site building loads, site base load is 1 MW.

**Test Activity (This information may be repeated for different technologies and systems):**

**Test Objective:** Technology evaluation, performance characteristics

**Type of technology or system:** All Microturbine Generators Available: To date includes Capstone Model 330 and Bowman Power Systems 45 kW and 60 kW combined heat and power units. The latter produce 4-8 therms/hr each of hot water.

**Size of system:** *(See above)*

**Duration of testing:** Variable based on unit, Capstone 330 5800 hours to date, BPS 45 about 180 hours and BPS 60 about 110 hours

**Test Dates:** Capstone Model 330 ongoing, BPS 45 Jan 99 through Jun 99, BPS 60 Jun 99 through Nov 99

**Purpose of testing:** Determine performance characteristics and state of development for commercially available microturbines

**Type of data collected:** Kilowatts, Fuel flow, fuel pressure, fuel temperature, (for CHP units) water flow, water temperature at 15-minute intervals.

**Describe data collection software:** Commercially Available Campbell Scientific Data Acquisition System with Operator Interface Software, which operates on PC and MS Windows Op Sys. Access is either local through serial port or remotely via modem.

**Computer models used at Facility:** None

**Recent Publications/Papers:**

By Stephanie L. Hamilton

"Microturbines poised to go commercial," *Modern Power Systems*, September 1999

"The Buzz is from the Micro Turbine Generators," *Deregulation Watch*, Vol. 2, No. 14

"Project Title: The Micro Turbine Generator Program,"HICSS-33 Conference, January, 2000

## 2.3 University of Alaska - Fairbanks Energy Center

**University of Alaska - Fairbanks Energy Center**
***Survey of Test/Lab Facilities***

**Date of response:** 2/2000

**Facility Name:** UAF Energy Center

**Facility Location (City, State):** Fairbanks, Alaska

**Contact Information:**
Management (Name, phone/fax, e-mail): Ron Johnson, ffraj@uaf.edu
Technical (Name, phone/fax, e-mail): Dennis Witmer, ffdew@uaf.edu

**Facility Ownership (Industry owned, Government funded, University, Other grant support):** University of Alaska, support from USDOE

**Operational Date (Date facility was commissioned or commenced testing activity):** 8/99

**Staffing:**
Professionals: 4
Technicians: 3
Operators: 3

**Current Funding Level:** $500K/yr

**Dominant Funding Source:** USDOE

**Size of Facility (Estimated area in square feet or acres, number of buildings, number of test bays, fenced enclosures):** 1000 $ft^2$ lab space inside warehouse of 6000 $ft^2$, outdoor testing space, 5 test bays with utilities, fume hoods and combustion exhaust removal

**Describe any specialized test equipment used:** Labview-based DAS, FTIR

**Grid-connected or stand-alone:** Stand alone

**Test Voltages and Power levels:** (0-100), (0-5 kW)

**Types of loads used for testing (Passive, active; resistive or induction and indicate sizes in kW or MW):** Resistive with variable loading, computer controlled Dyanload

**Test Activity (This information may be repeated for different technologies and systems):**

**Test Objective (Technology evaluation, performance characteristics, technology development support):** All of above

**Type of technology or system:** Fuel cells & reformers

**Size of system (Power rating – kW or MW; Energy rating – kWh or MWh; for storage systems):** 0-5 kW

**Duration of testing:** few hours at time over past 8 months

**Test Dates (Indicate if on-going, or expected end-date):** On going

**Purpose of testing:** See test objective

**Type of data collected (Parameters, number of channels, sampling frequency; Attach a sample data dump):** Voltage, current, T, P, flow rate, in order to obtain thermodynamic energy balance

**Describe data collection software (Commercial application software or internally developed; capability, operating system platform):** Labview software and hardware, control and data acquisition developed in house on this platform.

**Computer models used at Facility (Commercial or developed in-house; current and past usage):** Apple G3's; starting to use Simulink

**Recent Publications/Papers:**

Johnson, R., D. Witmer, D. Das, and H. Rueter, 2000, The Creation of the UAF Energy Center, Jl. Cold Regions Engr.

Witmer, D., R. Johnson and J. Keller, 1999, Remote Area Power Program Alaskan Villages, Proceedings of National Hydrogen Association National Meeting, Tyson's Corner, VA. April 7-9

Witmer, D., T. Johnson, R. Johnson, D. Morse, S. Guthrie, and J. Keller, 1999, Fuel Cell Utilization Measurements of PEM Fuel Cells for Remote Power Applications, Proceedings of National Hydrogen Association National Meeting, Tyson's Corner, VA. April 7-9

## 2.4 WisPERC/WEMPEC Labs

**WisPERC/WEMPEC labs**
**(University of Wisconsin – Madison)**
***Survey of Test/Lab Facilities***

**Date of response:** January 26, 2000

**Facility Name:** WisPERC/WEMPEC labs

**Facility Location:** Madison, Wisconsin

**Contact Information:**
Management (Name, phone/fax, e-mail): Kathy Torok, 608-262-3934, Fax: 608-262-5559, Torok@engr.wisc.edu
Technical (Name, phone/fax, e-mail): Ray Marion, 608-262-6725, Fax: 608-262-5559, Marion@engr.wisc.edu

**Facility Ownership:** University of Wisconsin-Madison

**Operational Date:** 1980

**Staffing:**
Professionals: 8
Technicians: 2
Operators:

**Current Funding Level:** $3,000,000+

**Dominant Funding Source:** Government and industry

**Size of Facility:** 6500 sq. ft., 20 test benches

**Describe any specialized test equipment used:**

| | |
|---|---|
| **Variable ac sources:** | Two Staco 480V 3 phase 35A |
| | Two Variac 240V 3 phase 45A |
| **Power analyzers:** | Xitron 2503 |
| | Vahalla 2300 |
| | Two Yokogawa 2533 |
| | Five Fluke 41 |
| **Dynamometers:** | 50 HP 6000 rpm |
| | 30 HP 6000 rpm |
| | 30 HP 3600 rpm |
| | Three 1 HP 4000 rpm |
| **Torque measurement:** | Himmelstein transducers (2000, 1000, 500 in-lb) |
| **Tachometers:** | Two Yokogawa 3632 |
| **Machine bases:** | Ten 8 ft x 3 ft concrete |

| | |
|---|---|
| **Oscilloscopes:** | Nine LeCroy (100-500 MHz) |
| **Voltage measurement:** | 15 Tek P5200 Differential probe |
| | 4 Tek P5210 Differential probe |
| | Preamble preamplifier |
| | Five Nicolet Isobe 3000 |
| **Current meas:** | Eight Tek 503/A6303 |
| **Calibration:** | Vahalla 2703, 2500 |
| **Gaussmeter:** | Bell 9900, 4048 |
| **Spectrum analyzer:** | HP L1500A, 3582A, 3561A |
| **LCR meter:** | Quadtech 7600 |
| | HP 4263A |
| **Device tester:** | LEM TRi 6015 |
| **Environmental chamber:** | Envirotronics EV33-2-705 (-73C/+177C) |
| **Computer software:** | Labview |
| | Orcad suite |
| | Magsoft |
| | Maxwell |
| | Matlab |
| | EMTP |
| | Saber |
| | Mathcad |

**Grid-connected or stand-alone:** Both

| | |
|---|---|
| **Test Voltages and Power levels:** | 480 V, 3 phase (200A, 100A, 50A) |
| | 240 V, 3 phase (100A, 50A) |
| | 120/208V, 3 phase (100A, 50A) |
| | 115/230V DC (70A) |

| | |
|---|---|
| **Types of loads used for testing:** | 150 kW, 480 V three phase resistive load |
| | Induction motors: |
| | Five 460V (5-40 HP) |
| | Fifteen 230/460V (3-30 HP) |
| | Six 230V (1-30 HP) |
| | Eight 120V (5-25 HP) |
| | Adjustable speed drives up to 50 HP |

**Test Activity:**

| | |
|---|---|
| **Test Objective:** | Distributed UPS systems control |
| **Type of technology or system:** | Flux vector control |
| **Size of system:** | 50 kW |
| **Duration of testing:** | 2 years |
| **Test Dates:** | 1997 |
| **Purpose of testing:** | Establish feasibility |
| **Type of data collected:** | 4 channels – dc link voltage, inverter output voltage inverter output current and control signals |

**Test Activity:**

| | |
|---|---|
| **Test Objective:** | Low loss inverter technology development |
| **Type of technology or system:** | Auxiliary resonant commutated pole converters |
| **Size of system:** | 50 kW |
| **Duration of testing:** | 2 years |
| **Test Dates:** | 1998 |
| **Purpose of testing:** | Establish feasibility |
| **Type of data collected:** | 4 channels – dc link voltage, inverter output voltage inverter output current and control signals |

**Test Activity:**

| | |
|---|---|
| **Test Objective:** | Control of harmonic currents |
| **Type of technology or system:** | Active filters |
| **Size of system:** | 50 kW |
| **Duration of testing:** | 2 years |
| **Test Dates:** | 1999 |
| **Purpose of testing:** | Establish feasibility |
| **Type of data collected:** | 4 channels – dc link voltage, inverter output voltage inverter output current and control signals |

**Test Activity:**

| | |
|---|---|
| **Test Objective:** | Advanced inverter technology development |
| **Type of technology or system:** | Multilevel inverters |
| **Size of system:** | 50 kW |
| **Duration of testing:** | 2 years |
| **Test Dates:** | Ongoing |
| **Purpose of testing:** | Establish feasibility |
| **Type of data collected:** | 4 channels – dc link voltage, inverter output voltage inverter output current and control signals |

**Describe data collection software:** National Instruments Labview

**Computer models used at Facility:** PCs (Win 95/98/NT/2000); HP workstations; Macintosh

## 2.5 Arizona Public Service Company (APS)

APS operates a Solar Test and Research (STAR) center in Tempe, AZ, to test renewable energy systems. The STAR facility occupies several acres and was commissioned in 1988 to research utility-specific issues related to the use of PV in utility applications. Today the scope of STAR has expanded to include test and evaluation of a broad range of renewable and other generation technologies including PV (flat panel and concentrating), fuel cells, parabolic dish (Stirling engines), battery and hydrogen generation/ storage and microturbines. In addition to the generation and storage technologies, STAR has developed considerable expertise in power conversion and balance-of-plant areas that supports its overall mission.

The installed capacity of PV systems depends on the particular PV systems on test at the time but it generally is about 200 kW. In addition to the PV, there are two microturbines (Capstone and Allied Signal), two dish Stirling systems and a hybrid diesel/battery system that provides power to the STAR.

Given the current scarcity of internally funded research by electric utilities, STAR is one of the few remaining utility-owned facilities of its kind. The data gathered at STAR in the different technologies could be potentially useful for CERTS for its modeling activities in the distributed resources task.

Figure 1 shows a partial view of the large area occupied by the STAR facility. Not shown in this view are dish Stirling systems and the concentrating PV arrays.

**Figure 1. Partial view of the APS STAR Facility.**

## 2.6 Sandia National Laboratories

Sandia National Laboratories (SNL) has a wide range of test facilities that support its renewable energy, energy storage and fuel cell technology development programs. The test facilities located both at the Albuquerque and Livermore campuses support test activities in PV, dish Stirling, small fuel cells, battery storage and wind turbines through a remote test site located at the Conservation and Production Research Laboratory in Bushland, TX.

The National Solar Thermal Test Facility (NSTTF) and the Photovoltaic Systems Evaluation Laboratory (PSEL) are the two main centers for testing PV and dish Stirling systems that are of interest to CERTS. Figure 2 shows an aerial view of the 9 acre NSTTF that includes the heliostats and tower for central receiver testing, two 11 meter parabolic dishes each rated at 75 kWt, parabolic troughs and a Solar Furnace. Currently, the facility is testing a 10 kW grid-connected Stirling engine.

The PSEL has two 30 kW PV arrays that are used for PV technology development research and a few kilowatts of grid connected PV to support power conversion systems research. The PSEL also has a 750 kWh battery storage system.

**Figure 2. Aerial view of the NSTTF showing the heliostat field and tower with the parabolic dish and trough systems in the background at right.**

## 2.7 Oak Ridge National Laboratory

The Buildings Technology Center is planning the purchase of a Capstone 28 kW or an Honeywell microturbine generator for detailed performance testing in the combined heat and power mode. Their plans are to have the system operational by mid-2000.

Details of the test modes and data acquisition will be included in this document as they are made available by ORNL.

## 2.8 EPRI PEAC

The EPRI PEAC Corporation is developing a multi-technology test laboratory in Knoxville, TN, for testing distributed generation and storage technologies. The plans include test platforms for two flywheels, a fuel cell, and a microturbine. It is expected that the facility will be operational in late 2000.

The overall objectives are geared to meet utility needs as distributed technologies find increased penetration into the electric grid. These include gathering operational data, especially the interaction of several technologies operating in close proximity, technology evaluation and operator training. Although the facility is not operational at the time of this writing, it was included in the survey to recognize its potential contribution to future CERTS activities.

Appendix A includes a brochure describing the PEAC facility in greater detail.

## 2.9 Chugach Electric Association

Although Chugach Electric Association (CEA) does not have a dedicated test facility, their experience with fuel cells and microturbines and their electrically isolated grid uniquely qualifies them for inclusion in this survey. CEA has operated two 200 kW fuel cells on behalf of the National Guard and DoD for over three years. In addition to those two systems, they have recently installed another 4 fuel cells in Anchorage. CEA is also participating in a field demonstration program for microturbines sponsored by the National Rural Electric Cooperative Association through which they have received two micoturbines that will be installed in Anchorage.

CEA has acquired unique experiences in rebuilding the fuel stacks and making field modifications to make the systems work in remote locations. Their experiences have provided them a better understanding of system operational characteristics that are not always obvious from vendor supplied literature. The fuel cells they operate are instrumented to record detailed operating data that may prove useful for the CERTS modeling activities and they have expressed a willingness to share data with CERTS as needed.

# 3. Focused Assessment of DER Facilities for Testing Aspects of the CERTS Microgrid Concept

Since the time of the initial survey, CERTS has articulated a concept for integration of distributed energy resources called the CERTS Microgrid (Lasseter 2002). The CERTS Microgrid envisions a collection of microsources that present themselves to the grid as a single entity and seamlessly transition to an islanded system if the grid goes away. Key to their operation in a Microgrid mode is that at least one of the sources within this group is dedicated to meeting the thermal energy needs of the local load it serves.

Testing the CERTS Microgrid concept will be critically important to validate and demonstrate the underlying features of the CERTS Microgrid such as the ability of each source to control its voltage and power autonomously, protection and relaying for a system that operates both in grid-connected and stand-alone mode and to demonstrate the feasibility of the multiple sources within the microgrid to share loads and respond to fast load changes.

This evolved concept of the CERTS Microgrid required that the test facilities where it would be tested have different technical and staffing capabilities than was initially perceived which prompted revisiting at least one site that was previously surveyed, and adding another test site to the survey population. Considerations such as the active participation of an electric utility in the test phases added stronger relevance to utility ownership of the test site. This section discusses the CERTS Microgrid concept and identifies the conceptual test configuration and the requirements of the test site to successfully meet the testing needs for the CERTS Microgrid.

## 3.1 Summary of Testing Requirements for CERTS Microgrid Concept

The test bed under development to test and validate aspects of the CERTS Microgrid concept is composed of a 480volt network of three Capstone 30 kW microturbines separated by a (simulated or physical) separation of approximately two hundred feet. The lower voltage has significant impacts on the test requirements for the Microgrid and consequently the capabilities set for the test site. Figure 1 is a schematic of the Microgrid in its present configuration; the important consideration is the fact that it is entirely a 480volt network to the step-down or isolation transformer at the Point of Common Coupling (PCC) shown on the left.

The test network will be interspersed with different types of loads including motors, nonlinear, “digital” and unbalanced loads that effectively simulate real applications. The three Capstone microturbines will be specially modified for the test bed to include enhanced control capabilities to regulate power flow and voltage as loads change and the ability of each machine to rapidly pickup its share of the load when the Microgrid islands. These modified Capstone microturbines will be furnished by CERTS to the test facility for the duration of the test program.

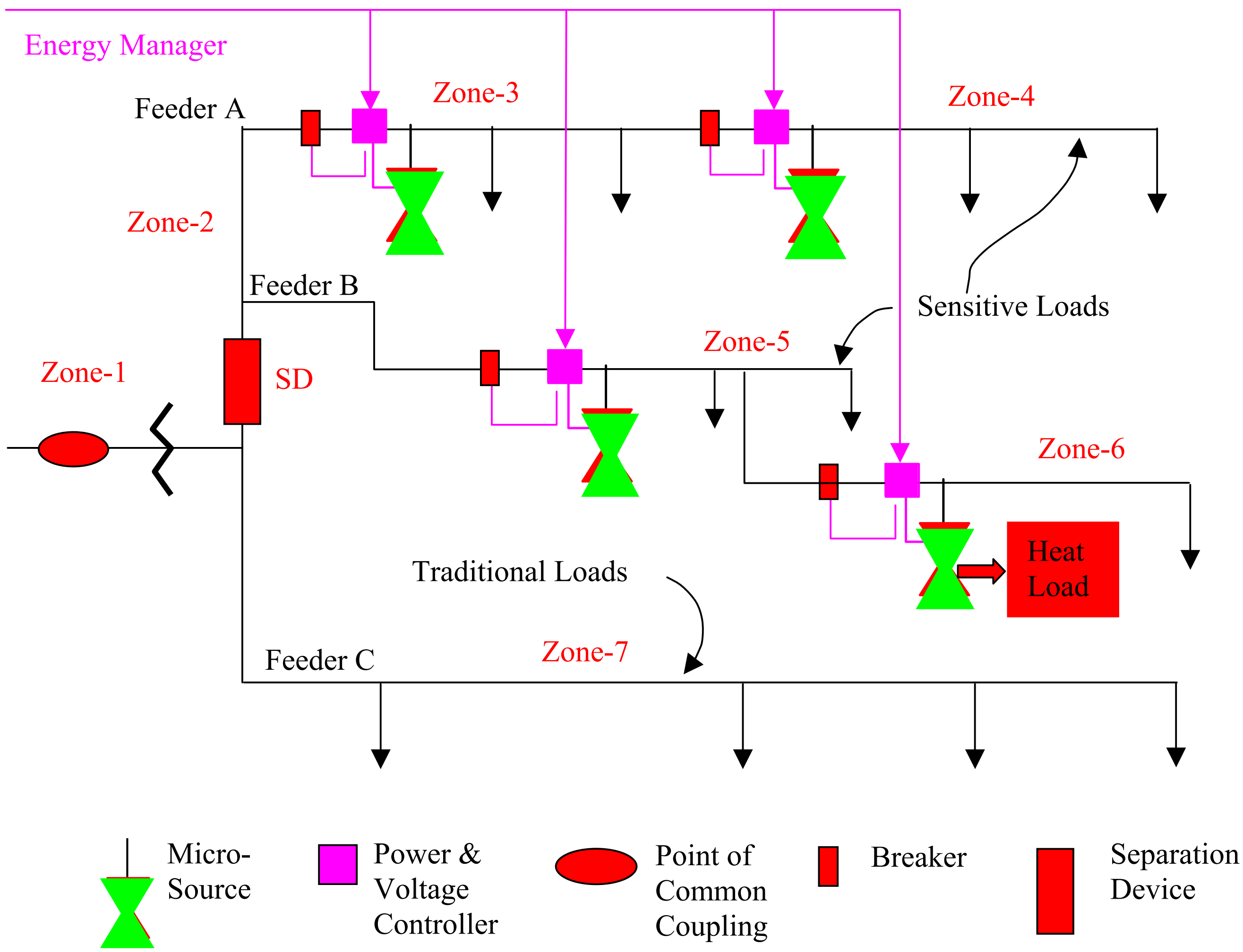


**Figure 1. Microgrid Schematic.**

The requirements that emerge for the test facility based on this testbed configuration are divided into three categories: Existing test facility equipment and layout; Staff facility availability and expertise; and Utility ownership and commitment.

### 3.1.1 Existing Test Facility Equipment and Layout

The three modified Capstone microturbines form the core of the testbed. Since these will be furnished by CERTS, this criteria focuses on the test equipment and instrumentation that can simulate and record the test data. For example, the ability to generate sub-transient grid conditions and capture the response of the test Microgrid in suitable sub-cycle time frames is important. The layout of the facility must include sufficient space to accommodate the test configuration in suitable outdoor or indoor setups. In the previous survey, there was some consideration of the test facility interface with the supplying utility's grid. The stiffness of the grid was a consideration, with a bias towards a weak distribution leg in order to exercise the Microgrid testbed through a range of distribution feeder faults. However, with the lower voltage of 480volts, and with only three 30 kW microturbines, the stiffness of the feeder to the test facility is no longer a consideration. For the smaller size and voltage range of the test setup, grid stiffness could be simulated by incorporating appropriately sized transformers at the testbed interface. The actual test plan for the Microgrid test will determine the equipment necessary to perform the testing. However, most of the data recording and analyzing hardware necessary to support the testing should be available at established test facilities. If the test requires specific items that are not available at a test site, then it is expected that this equipment will be leased or purchased as suitable.

### 3.1.2 Staff/Facility Availability and Experience

The availability of the test facility and its support staff during the testing period is an important consideration in carrying out the tests. The experience base of the staff must include a demonstrated understanding of protection issues for stand-alone systems and extensive experience with inverter-based sources such as photovoltaic, microturbines or energy storage systems.

### 3.1.3 Utility Ownership/Commitment

The commercial acceptance of the Microgrid and its successful use in real-world applications requires that its operating characteristics and behavior be thoroughly understood by utility protection and distribution engineers. This is most likely to occur if the Microgrid is tested and the data shared with the utility engineering community on an on-going basis. Utility ownership and staffing of the test facility where the Microgrid is tested is the most expeditious manner through which such acceptance could occur. While there are several utilities that have and continue to conduct testing of DG sources, the criteria in this instances seeks to recognize those utilities that have a long term commitment to DG testing and evaluation. This requires that the utility have an established test facility with a commitment to its operation to support the evaluation of a variety of DG sources. This commitment is evidenced by suitable staffing of the facility, availability of test equipment and an on-going effort to seek new DG sources to evaluate their performance in a range of operating environments. The criteria excludes those utilities that have tested DG sources on a one-time basis, or conduct short-term testing on an as-needed basis to gain familiarity with a particular DG system. Hence, utility ownership in this perspective includes not only the ownership of the test facility, but implies the presence of a sustained program within the utility to investigate and characterize the performance of DG sources.

## 3.2 Development of Additional Information on Existing Test Facilities

In preparation for laboratory testing of the CERTS Microgrid concepts, additional information was developed on two potential sites: American Electric Power's (AEP) Dolan Technology

Center, which was not included in the original survey, and Pacific Gas and Electric's San Ramon facility, which was included in the original survey. Information on the Dolan is summarized in the questionnaire format used in the earlier surveys. Narrative information from a site visit to San Ramon in September 2001 (for which a questionnaire had previously been completed) follows. The information collected during the site visit significantly updates the information reported earlier in the 2000 questionnaire.

### 3.2.1 AEP Dolan Technology Center

**AEP Dolan Technology Center**
***Survey of Test/Lab Facilities***

**Date of response:** 07/31/2002

**Facility Name:** AEP Dolan Technology Center

**Facility Location (City, State):** Groveport, Ohio

**Contact Information:**

**Management (Name, phone/fax, e-mail):** Dave Nichols.614 8364260(phone)/614 836 4168 (fax), dknichols@aep.com

**Technical (Name, phone/fax, e-mail):** Kevin Loving, 614 8364250 (phone)/614 836 4168 (fax), kploving@aep.com

**Facility Ownership:** Industry owned

**Operational Date (Date facility was commissioned or commenced testing activity):**

**Staffing:**

Professionals: 15
Technicians: 4
Operators: 1

**Current Funding Level:** $20M

**Dominate Funding Source:** Strategic Corporate Technology

**Size of Facility (Estimated area in square feet or acres, number of buildings, number of test bays, fenced enclosures):** There are two separate test areas identified as DTC & Walnut.

DTC statistics: 2400square feet /multiple control buildings, outdoor facility, 1 test bay enclosed with 5 psi gas supply, protection package

Walnut statistics: 1.5 acres, multiple control buildings, outdoor enclosed facility, 2 x 1.5 MW test bays (+ 2 future bays) 200psi gas supply, protection package

**Describe any specialized test equipment used:** 3 phase 250 kW rated Sag generator, 3phase voltage reclosers, 3 phase voltage regulators, controllable circuit breakers, industrial load banks, multiple transformer banks, protective barriers, automated switching controls, complete utility approved protection package, wireless and other advanced communications methods are available. Various Data Acquisition systems, analog and digital recorders, fiber optically isolated Das, power quality measurement devices, Electromagnetic Interference Measurement, revenue grade wattmeters and other in-house developed instrumentation packages designed for DR testing, monitoring and control. Equipment is used to create system disturbances and to assess compatibility.

**Grid-connected or stand-alone:** Both

**Test Voltages and Power Levels:** DTC – 480volt- 13.8 kV up to 500 kW (electrical)
Walnut – 480volt – 138 kV up to 10 MW. (electrical)

**Types of loads used for testing (Passive, active; resistive or induction and indicate sizes in kW or MW):** 4 resistor load banks (2.6 MW total), 100 kVar Reactive load bank, in-house developed non-linear, motor and industrial load banks, access to various building motor loads in grid independent mode, capacitive loads as needed.

**Test Activity (This information may be repeated for different technologies and systems)**

**Test Objective:** Technology evaluation, performance characteristics, technology development support, system compatibility testing, standards compliance testing, conformance to specification, new product development.

**Type of technology or system:**

**Size of system (Power rating – kW or MW; Energy rating – kWh or Maw; for storage systems):** Micro turbines, fuel cells, wind, solar & energy storage devices ranging in size from watts to 1.2 MW.

**Duration of testing:** Typical tests last from very short time periods (days) to months of testing, depending on test and development requirements.

**Test Dates:** continuous activity since September 1999

**Purpose of Testing:** Technology evaluation, performance characteristics, technology development support, system compatibility testing, standards compliance testing, and conformance to specification, new product development.

**Type of data collected:** Parameters, number of channels, sampling frequency. Varies depending on test requirements. Both long term and transient recording devices are available. Typical test involves measurement of ac and dc electrical, gas flow, environmental land power quality parameters. As many as 100 low speed and 50 transient (greater than 1Mhz response) can be measured using available instrumentation.

**Describe data collection software (Commercial application software or internally developed; capability, operating system platform):** We use a combination of in-house and commercial software. In-house development is based on Lab View software. Commercial software includes PMAC DAS, and products available with specific instrumentation – Metrosoft, Dranview, PASS, Metermate, PQView

**Computer models used at Facility: (Commercial or developed in-house; current and past usage):** In-house developed and DaDisp, Sigma plot & MATLAB

**Recent Publications/Papers:**

*Plans to Test Distributed Resource Products at Walnut Station*, EPRI DR Week, March 2002.

D. K. Nichols. *Electricity Delivery: Challenges and Solutions*. IEEE Power Engineering Society 2001 Winger Meeting, 28 January – 1 February 2001, Columbus, Ohio USA

D. K. Nichols and T. Oshima. *Sodium Sulphur Batteries: Service for Peak Energy Demand Periods*. The Sulphur Institute's International Symposium Sulphur Markets-Today and Tomorrow. Amsterdam, the Netherlands, March10-12, 2002

*AEP Experiences with Distributed Resources*, IERE Conference , June 2002

*System Compatibility Issues In siting Distributed Power*, Distributed Power conference , 2001

*Market Developments for sodium Sulfur Battery*, EESAT Conference ,

D.K. Nichols and T.Key ,Compatibility Testing of Grid-Connected Distributed Resources,PQA Conference , 2000

### 3.2.2 Description of PG&E Distributed Generation Equipment Testing Capabilities

Pacific Gas and Electric Company (PG&E) has a Technical and Ecological Services (TES) department that is housed on a 13-acre site in San Ramon, California. This facility employs over 140 engineers, scientists, and technicians working on a wide range of testing, analytical, and environmental projects. Projects include those focusing on failure analysis and service life enhancement, performance assessment, development and evaluation test equipment and measurement methods, environmental impact assessment, meteorological measurement and forecasting, instrument calibration and repair, and material and product evaluation. These projects are conducted by TES in 15 laboratories at the San Ramon site, and in the field with portable equipment.

The TES facility has significant capabilities for testing and evaluating distributed generation (DG) equipment. DG equipment can be tested in grid-connected and grid-independent configurations, as well as in simulations where the equipment is connected to the utility with simulated lengths of distribution line. The TES facility complies with all PG&E interconnection requirements of an independent power producer. The facility has an overall power rating of 500 kVA and has up to 2 MVA of load capability for switching within the facility. The facility has extensive measurement capabilities, including the ability to measure system conditions of temperature, pressure, flow, electrical properties, power quality, vibration, acoustics, and emissions.

The TES facility has the following specific capabilities for testing DG equipment:

- 500 kVA switchgear for independent power production, 2 MVA internal load capability;
- 3-phase, 480 Volt wye service;
- Multiple bus configurations for islanding capability;
- Protection for utility under/over frequency, under/over voltage, and ground fault current;
- 400 kW variable resistive load controllable in 5 kW increments;
- 300 kVar variable inductive load controllable in 3.75 kVar increments;
- Additional capacitance, resistance, and inductance can be added as required;
- Up to 30-mile simulated transmission line, variable in steps of 10 miles;
- One inch, 40 psi natural gas supply;
- 8-foot by 13-foot acoustic isolation enclosure for engine tests;
- 70-foot by 40-foot building designed for DG testing.

One limitation of the facility for very high voltage grid connection is that the facility's main transformers have variable voltage capability at 40 kV, 70 kV, and 200 kV, but the transformers cannot operate at the full transmission system voltage of 230 kV. When the transformers are connected to the 230 kV grid at the 200 kV setting, they eventually become over-excited and therefore can only operate for a few hours. Capabilities also exist to connect equipment to the facility's bus structure at 480 V and 21 kV, and it is unlikely that a microgrid test would require any greater capabilities than these. The 200 kV limit is therefore unlikely to represent any practical limit to the continuous testing of microgrid DG equipment.

The TES facility has been used for a variety of projects in the past. At present, the facility is not under intensive use, but it is currently being reconfigured for an upcoming project with Distributed Utility Associates and the California Energy Commission to test a few pieces of DG equipment. Past projects include those to evaluate cryogenic inverters, battery storage evaluations, performance testing of a 70-kW molten carbonate fuel cell, performance testing of natural gas gensets, simulation of photovoltaic systems in conjunction with inverter performance, evaluation of superconducting magnetic energy storage, and evaluation of a bi-directional 60-kW power converter to operate as a static VAR compensator or voltage source inverter.

PG&E Contact:

Bob Malahowski
Electrical Unit Supervisor
PG&E Technical and Ecological Services
3400 Crow Canyon Road
San Ramon, CA 94583
Ph: 925-866-5366
Email: RJMc@pge.com

**Figure 3. Equipment Testing Yard with Bus Structure in Background.**

**Figure 4. Closer View of Enclosed Equipment Testing Yard and Bus Structure.**

**Figure 5. Main Control Room.**

**Figure 6. View of Equipment Testing Yard from Control Room.**

**Figure 7. Indoor DG Equipment Testing Laboratory.**

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# 4. References


Lasseter, R., A. Akhil, C. Marnay, J. Stevens, J. Dagle, R. Guttromson, A. S. Meliopoulous, R. Yinger, and J. Eto. April 2002. *Integration of Distributed Energy Resources: TheCERTS Micro-grid Concept*.

Yinger, R, July 2001. *Behavior of Capstone and Honeywell Microturbine Generators During Load Changes*.

Feero, W, Dawson, D, Stevens, J, March 2002. *Protection Issues of the Microgrid Concept*.

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# Appendix A

## PEAC Facility Brochure

## Promising Technologies

In this, the new millennium, the certainty of a deregulated energy market is bringing innovative technologies to bear upon the fields of distributed generation and power-quality mitigation. Photovoltaics, microturbines, fuel cells, high-speed flywheels, ultra capacitors, and windmills are but a few of these exciting, progressive technologies for generating and storing electric energy. Although energy providers and their customers have enjoyed the first generation of these technologies, the next generation promises to trump their performance by increasing efficiency, extending storage time, and reducing the weight and size of the storage medium. However, before these technologies are pressed into service, they must be thoroughly evaluated to determine how they will interact with the existing power system, other end-use loads, and each other.

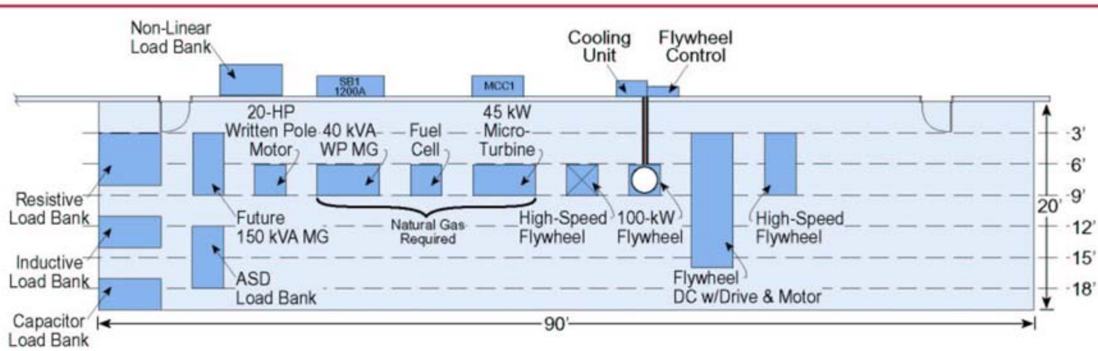
## An EPRI-Sponsored Research Project

EPRI PEAC Corporation, collaborating with EPRI, electric energy providers, and the manufacturing community, is developing a unique laboratory for testing and evaluating technologies for generating and storing electric energy. Adjacent to the Power Quality Test Facility, the Power Quality/Distributed Generation (PQDG) Park will be located in Knoxville, Tennessee, and will be managed

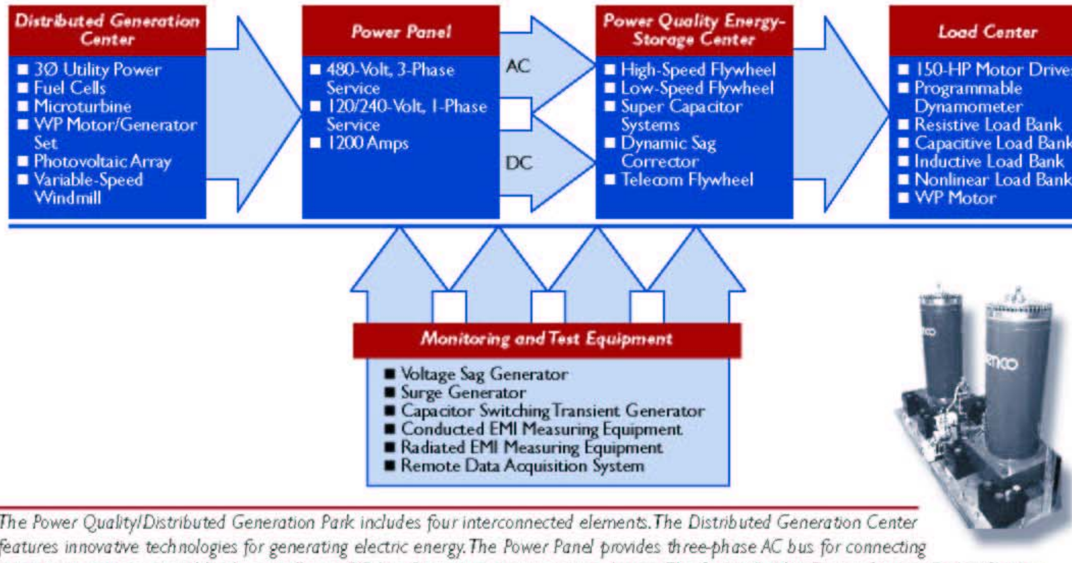
Microturbine

## Batteries Once But Not Forever

In addition to evaluating distributed generation technologies, a key goal of the PQDG Park is to evaluate alternatives to battery-based energy storage. Energy-storage technologies are classified by the medium that stores the energy. Mechanical energy can be stored in a rotating mass, such as high-speed and low-speed flywheels. Magnetic energy can be stored in superconducting material, such as the superconducting magnetic energy storage device, or SMES. Chemical energy can be stored in fuel cells and batteries. Although batteries are by far the most widely used type of energy storage in power quality mitigation devices, they are also responsible for most failures of uninterruptible power supplies. Batteries have a finite number of charge-discharge cycles, often require heavy maintenance, and pose an environmental hazard. Therefore, providers of electric energy and their customers are now searching for new energy-storage technologies that surmount the shortcomings of batteries. One such alternative energy-storage technology is the fuel cell, which can be used in both generation and power quality mitigation equipment.




*This 20-by-90-foot pad of the PQDG Park integrates the latest technologies in generation, mitigation, testing, and monitoring.*




Flywheels

*The Power Quality/Distributed Generation Park includes four interconnected elements. The Distributed Generation Center features innovative technologies for generating electric energy. The Power Panel provides three-phase AC bus for connecting generation equipment and loads, as well as a DC bus for testing energy-storage devices. The Power Quality Energy-Storage Center features technologies for storing electric energy. The Load Center features the types of loads commonly found in industrial environments, such as motors, drives, and programmable logic controllers, as well as fully adjustable resistive, capacitive, inductive, and nonlinear loads. The Park also includes state-of-the-art monitoring and test equipment that can be used at any point in the Park.*

by engineers renown in the field of power quality and distributed generation. Work on the Park began with the construction of the new EPRI PEAC facility in 1999. The Park is scheduled to be completed by the end of 2000.

## Join Us

EPRI PEAC invites energy providers to join this innovative research project. We also invite manufacturers of storage and generation technologies to participate by supplying their products and expertise.

### Early Joiners

- Tennessee Valley Authority (TVA): Switch Gear.
- Duke Power: Microturbine.
- Precise Power Corporation: Written Pole Motor.
- Teco Westinghouse: ASD and Motor.
- Urenco Limited: High-Speed Flywheel.
- Pillar Industries: Low-Speed Flywheel/Converter

## Value To Energy Providers

The Power Quality/Distributed Generation Park will enable providers of electric energy to:

- Train utility personnel on new power quality and distributed generation technologies.
- Provide the opportunity to identify emerging technologies that energy providers should evaluate as potential new channels of revenue and offerings to their customers.
- Provide a way to cost-effectively evaluate new technologies in a controlled environment by an unbiased third party to help energy providers identify potential strategic alliances.
- Study the interaction between these new technologies and other similar technologies, the power system, and end-use equipment.
- Verify the integrity of different interconnection schemes that incorporate these technologies, before the schemes are used in the field.

## For more information, contact:

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